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SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE, PUBLISHING THE OFFICIAL NOTICES AND PROCEEDINGS OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

FRIDAY, NOVEMBER 13, 1908

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

A TALK ON TEACHING[1]

IN speaking to you to-day upon the subject of teaching, I shall try to present some considerations, suggested by my own experience, in regard to the application of educational principles to our own problems. Much of what I shall say will doubtless be familiar to a body of teachers like yourselves. Yet it is perhaps desirable that even the commonplaces of education be brought before us from time to time; for, though we recognize the abstract principles that should be followed, yet it is only by constant attention to them that we shall succeed in making them the real foundation of our courses of instruction.

Throughout our considerations we must keep in view the aim of the education for which the institute stands. In regard to this there is, I believe, little difference of opinion. The aim is to produce men who have the power to solve the industrial, engineering and scientific problems of the day—men who shall originate and not merely execute. The fundamental question is, then, How shall we develop this power? It is *power* that counts, and not *knowledge*. The ultimate test is what a man can *do*, not what he *knows;* and this is the test we should apply to our students upon the completion of each subject of in-

[1] Given at a conference of members of the instructing staff of the Massachusetts Institute of Technology on March 20, 1908. To Professor H. G. Pearson I desire to express my great indebtedness for his suggestions and assistance in connection with the preparation of this paper for the printer.

struction, and to our graduates at the close of their period of study at the institute.

It is true that a part of the power of a scientific man depends upon his knowledge; and a part of our task as teachers consists in bringing him into permanent possession of those kinds of knowledge which are most essential. In connection with this work of imparting knowledge I ask you to note three kinds of errors into which we are especially apt to fall.

First, it is a common mistake to ply the student with more than he can possibly assimilate. For covering a certain subject we are allowed a limited number of hours; into that time we feel that we must crowd, at any rate, all the obviously important topics. This we make the consideration of prime importance, whereas we should first determine what principles and essential facts can, in the amount of time given, be treated with sufficient thoroughness to enable the student really to comprehend them and make them his own. We must, therefore, constantly examine the courses that we are giving, to see whether they are not overcrowded; and, if they are overcrowded, we must consider how they may be disencumbered, so that the main points may be properly emphasized. *Obiter dicta* have no place in a course of instruction: principles which there is not time to drive home should not be mentioned at all; for they simply confuse the student, by distributing his attention over a larger number of topics than he can possibly assimilate at one time.

The existing conditions make the commission of this error only too easy. There is a constant demand that we give our students a wide variety of information. Not to teach a phase of a subject which may be regarded as important invites criticism and argues incapacity on the part of the teacher. Moreover, in many subjects we are badly off in the matter of text-books: most of our so-called text-books are really treatises and reference books. Would that some competent person would write for a ninety-hour course in chemistry or physics a text-book containing only those facts and principles that can be properly taught in a ninety-hour course! It is this defect which has led so many of the institute professors to prepare notes of their own, the object of which is primarily to emphasize the more fundamental principles of the subject.

Notwithstanding these difficulties, however, it is our clear duty as teachers constantly to endeavor not so much to teach many things as to teach well—not so much to "cover the ground" ourselves, as to make sure that our students go over the course with us. In trying to include too much, we not only sacrifice the opportunity for training, of which I shall speak later, but we accomplish far less than we might even in the matter of imparting knowledge.

The second error of which I would speak is the failure to keep sufficiently in touch with the mind of the student—to appreciate the knowledge which he actually possesses and the degree of development of his mental powers. The unfortunate results of this error are most clearly and frequently observed in lecture courses. The lecturer is apt to look at his task merely from an objective view-point: if he presents his subject clearly and logically, he complacently feels that he has done his part, and that it is the fault of the student if he has failed to profit by it. Yet the real test of the success of a lecture course, as of any other form of instruction, is the amount of benefit that the student actually derives from it; and the teacher must frequently, by some means or other, apply this test, must consider the causes of his incomplete success, and introduce such modifications as seem likely to lead to better results. He must keep in touch

with the student so that he may appreciate his difficulties. This can be done much better in recitations than in lectures, but best of all through personal conferences; and, when conditions make it necessary to give lectures at all, they should be largely supplemented by these means, so that there may be individual contact with the student. It is to be hoped that the plan of regular conferences for which formal provision has already been made in first-year English and mathematics may be soon extended to other subjects; but in the meantime much is being done in this direction in an informal way by many of our best instructors. I wish only to emphasize the idea that such efforts are a well-paying investment of the teacher's time. They not only enable him to assist the individual student in a variety of ways, but they show the teacher the defects of his own methods of presentation and establish a cordial relationship between him and his class.

One important cause of this imperfect adaptation to the mental needs of the student is the lack of correlation between the different subjects of instruction. A teacher ought to know both what the student has already learned in his previous courses and what he will need to know in the later dependent subjects. To this end it is important that instructors should attend exercises in other subjects than their own, examine the text-books used, the notes and problems given out, and the experiments performed. For example, every instructor teaching applied mathematical subjects in the higher years of the various courses should familiarize himself with the new plan of teaching mathematics which has been recently introduced. I believe, in a large school like the institute, the imperfect correlation of the different subjects of instruction is one of the most serious evils, and one which must be met by an increased effort on the part of each instructor to know about the work that is being done in subjects related to his own.

The third difficulty which I would refer to is that which arises from the tendency of the student to learn by memorizing and to do his work in the laboratory mechanically, without thinking. We must not allow ourselves merely to mourn over the fact that the average student won't think if he can help it, or try to justify our failures to get him to do so by reflections on his earlier education. We must face the situation as it actually is, and realize that it is one of the most important parts of our problem to make the student think.

Herbert Spencer is reported to have said, "if he read as much as other people, he would know as little as they." The remark is worth remembering, in spite of its complacency, for the light it throws on the worthlessness of whatever is done without thinking. In science, as in other departments of knowledge, no acquisition is real and permanent which is not won by hard thought. As every teacher knows, a most effective way of making a student think is by constant questioning. He emphasizes a principle by asking questions about its possible applications. He answers one question by asking another, and, if possible, gets the student to put the questions for himself. The good teacher is constantly trying to lead the student on, but he refuses to carry him. In the laboratory and drawing-room, where students tend to work as if their whole purpose were to go through the mechanical operations as rapidly as possible, the successful instructor will be constantly on the alert to check this tendency. He will be with the student at his desk as much as possible, not telling him what to do, but seeing that he understands and plans out his work for himself. Only in matters of manipulation and technique should a distinctly different

plan of instruction be adopted. Here, in order to economize time for more important work, the effort should be made to give the student the necessary manual skill as rapidly as possible, by giving him detailed instruction and showing him by example the little artifices that make the expert manipulator. The engineer, architect or chemist must have a good technique, and we can not afford to neglect it; but one of our problems is to reduce the time needed for its acquirement to its lowest limit.

Summing up now this discussion of the question of imparting knowledge, I would advise especially:

1. That we take care not to include in our courses more than the average student can properly assimilate.

2. That we keep in close touch with the actual knowledge and mental development of the student; that to this end we introduce recitations and invite individual conferences as far as possible; and that we inform ourselves more fully in regard to the work which is done in courses related to our own.

3. That we discourage the habit of memorizing and of working in a thoughtless, mechanical way in the laboratories and drawing-rooms by close personal contact with the student and by appropriate modifications of our courses and of the examinations upon them.

I come now to the other more important and more difficult task of giving the student the mental training upon which the power of handling new undertakings and solving new problems depends. In comparison with this the imparting of knowledge is an insignificant matter. One of our professors has given an apt illustration of the true function of the institute. It should be, he says, a gymnasium where the faculties are exercised and developed, and not a boarding-house where the students are crammed with facts. We want our young men to acquire the power of solving problems; and this, like any other faculty, can only be developed by constant exercise of it. Therefore, we must make problems one of the main features of our courses—problems in the broadest sense, not merely numerical applications of principles. Class-room and drawing-room and laboratory work alike must consist largely in the solution of problems.

This matter of problems seems to me of so much importance that I would like to consider it with you in some detail.

First a few words as to the character of our problems. In the lower schools the questions given out for solution are well called "examples": that is, a teacher does a problem in a certain way, as an example; and the students learn by imitation to do others like it. Of course, for our purposes this kind of problem-solving is of scarcely any value. We must avoid problems which are only pattern-work and those which are simply the substitution of numerical values in formulas. One of our professors who makes problems a large part of his course told me of the student who came to him with the complaint that he couldn't do his problems because each one was different from the others, well showing the kind of problem-work to which he had been accustomed.

There are two classes of problems that are essential to our work—the kind that develop logical thinking or reasoning power and the kind that develop imaginative thinking or the power of planning and originating. For each of these two kinds of problems we should try to make better provision; but the latter kind needs, I believe, special development at the institute. For example, we ought to a greater extent require in our laboratories that the students plan out their own experiments. Students should be told what apparatus is available and what results are wanted, and

then should be left largely to their own ingenuity to produce those results. In each particular line of study there is, moreover, a particular form of problem-work that is appropriate. In engineering subjects it is the design of new structures and of new machines; in the descriptive sciences it is the identification of materials (provided this be done not by tables nor by a set method of procedure, but by the student himself upon the basis of his own knowledge); in English it is the writing of themes; and so on. Each teacher must consider how his subject can be presented so as to afford the largest opportunity for developing the student's reasoning power and creative ability.

Permit me next to say a few words in regard to the importance of independent work in the solving of problems. I believe that only by insisting upon this can anything like the full benefit be secured. In the first place, what we want to do is not to teach the student how to solve certain particular problems, but to train him in original thinking—to solve any kind of problem; and to this end he must do the work himself. Secondly, the line can not be effectively drawn at any other point than that of absolute independence. If one allows working together at all, some students will copy, and a still greater number will get other students to do all the thinking for them. Then, again, if problems form a large part of the term's work, the marks of the term ought to be based principally upon those problems; and this is not fair unless we are able to assure ourselves that the results represent individual work. When this requirement is made of the student, the instructor must be ready to assist him in his difficulties, and must provide definitely for opportunity for consultation; else the conscientious student will waste an undue amount of time before some obstacle which a few minutes' talk with the teacher would remove. It is, I think, very desirable to introduce more extensively the plan, already followed in some subjects, of requiring problems to be done at assigned hours under the guidance of the instructor rather than in outside hours of preparation. I am well aware that there are some advantages in allowing students of the same proficiency to work out their problems together: difficulties are overcome with less loss of time, the principles involved become clearer by discussion, and the work is made more attractive. In exceptional cases, especially with small classes of rather advanced students, who have acquired the true point of view, these advantages may be secured without incurring the evils to which I have referred; but I believe that this is true only in such exceptional cases, and that the difference in the emphasis laid upon independent work by different instructors is a source of demoralization to our students.

The introduction of more problem work naturally carries with it the laying of greater weight on the term work and less on the final examination in determining the record of the student—a thing which is in itself highly desirable. An instructor is sometimes heard to say, "If a man gets the subject in the end, it is all right." That remark shows, I think, that he does not have the true conception of the main purpose of his course, which is not to give a certain amount of knowledge in the subject, but to give a mental training which can only be acquired gradually by persistent effort through the whole term. Indeed, in my own opinion, one of the most effective means of raising the standard of our instruction is the abandonment of final examinations in more of our courses. Thereby not only are the many serious evils of the examination system removed—such as the postponement of serious study till the end of the term, the cramming dur-

ing a short period before the examinations (which is, I believe, wrongly regarded by some instructors who do not appreciate the character of cramming methods as valuable in affording a review and perspective of the whole subject), the attendant nervous strain and injury to health, the evils of tutoring and proctoring—but also because it impresses upon both instructor and student a different educational ideal, that of training the mind rather than storing it with knowledge. Some years ago the faculty took the step of abolishing final examinations in many first- and second-year subjects. I think the time has come when provision should be made by individual instructors and by the faculty for the extension of this plan to many other subjects.

These considerations may be summed up by saying that *problem-solving* is by far the most effective means we have of developing mental power. We must make such work as large as possible a part of our courses, making place for it by the omission of much other material, important though it may be. We must insist on independent work in the solution of problems, but in doing it we must be ready to give assistance to the individual student. Our examinations should be made a test of his power to handle problems connected with the subject rather than a test of his knowledge; and the record we give him should depend mainly on his success in this direction.

Let me pause here to make one remark, lest I should seem to underestimate the success which is already being attained by the teachers of the institute. Any one familiar with our work well knows that what I have said in regard to the relative importance of knowledge and training and the methods of developing mental power is only an expression of the general educational policy of the institute, and that the principles I have discussed have already been extensively put into practise here—probably to a greater extent than in any other large educational institution. I have emphasized these principles only in the hope of impressing each individual instructor more fully with their importance and of encouraging him to aim to base his own teaching upon them as largely as possible.

So far I have considered only that side of our work which relates to the professional training of the engineer or the scientist; but, as we all know, the problem of the institute is not confined to this. It is our function to give a general education in combination with a professional training—to educate the man as well as the engineer. We must constantly bear in mind this twofold aspect of our work, and must be contented to sacrifice in some measure professional attainment in the interest of a broader education. We must aim to develop those qualities which are the result of a liberal training—breadth of view, perspective and soundness of judgment; but we must especially aim to develop character and high ideals. The acquirement of *power* is, as I have said, the intellectual goal towards which we are striving; but we must also keep in view the moral end, which is the cultivation of the spirit which will lead that power to be devoted to some high form of *service*.

Some may perhaps contend that these are not our functions—that our obligations are only on the intellectual side, that the development of the moral, social, esthetic and physical qualities of the student are to be left to outside influences. Such a view is, in my judgment, a seriously mistaken one. It might well be held by the authorities of a graduate school of the purely professional type; but it is quite inconsistent with the conception of the institute as an undergraduate school, whose

primary function is to furnish an effective form of general education. Our students come to us during four years of the most critical period of life, when their habits of thought and ideals of life are being formed; and we must appreciate the seriousness of the trust which is thereby imposed upon us. It is of comparatively little significance whether the student acquires more or less knowledge of mathematics, chemistry, physics or engineering; but it is vitally important that his mental power, his general culture, his character and his ideals be adequately developed. We must, therefore, take care not to interpret our function as teachers too narrowly; but we must each of us improve every opportunity for contributing to the more general and more important result which the institute has in view. The means for attaining this result certainly deserve especial consideration in a talk on teaching. I have already expressed my ideas at some length on the development of mental power. Owing to the limited time remaining, I shall not attempt to discuss the means of developing those important qualities which are summed up in the word "culture"; but I should like to consider with you briefly the still more vital question of what can be done to develop character and high ideals. The indefiniteness of the methods by which this may be accomplished makes the subject a particularly difficult one; but it must not be passed over on this account.

The methods of the institute are especially adapted to develop those habits which go to the formation of character. To meet the demands of our curriculum, the student must be willing to subordinate pleasure to duty; he must work industriously and persistently; he must, too, work rapidly, whereby he comes to appreciate the value of time. Our scientific courses offer, moreover, special opportunities for inculcating habits of accuracy, reliability, clearness of expression, neatness and orderliness; and we must insist that the work be so carried out that these benefits do in fact result. Careless or slovenly work of any kind must be vigorously condemned. We should see that note-books be kept in a neat and orderly manner; that reports be written clearly in good literary form; that in the class-room accuracy of expression be cultivated; that the numerical work connected with problems be accurately performed (nothing like full credit being given when merely "the principle is correct"); and that every reasonable effort be made to verify an experimental result or confirm a conclusion before it is accepted as final. The teacher of any science who says it is not his business to attend to these things does not, in my opinion, understand his business, which is not so much to teach the subject-matter of the science as it is to teach *scientific method* and to cultivate the *scientific spirit*.

Yet the formation of character, important as it is, is by no means the whole of this side of our task. The qualities that make up a good character in the narrower sense are, after all, only "the half-virtues which the world calls best." That the man may be really effective, these must be supplemented by high ideals of service, a strong purpose in life, and a real devotion to it. With respect to means of imparting such ideals, I have only a few thoughts to present.

In the first place, I believe that, to accomplish much in this direction, we must get into personal relations with the student. Thereby many different opportunities of influencing him are opened to us. To begin with, we set him the example of rendering unselfish service to others by giving him individual aid beyond that which our formal obligations in class-room and laboratory demand. Let us make it clear to him

that it is not our primary purpose to "maintain the standard," but that we are personally interested in aiding him to fulfil the established requirements. Up to the end of the course the teacher should consider every student who is doing unsatisfactory work as one of the problems for which he must try to find a solution; and there is, I believe, no better way of securing attention from a student who is neglecting his work or of bringing up to the standard one who is having difficulty with the subject than by showing a personal interest in him. I know that this makes an added demand on the instructor, and that what any one can do in this way is limited; yet it is an aim to be kept in mind and to be striven for. Since at the institute there is one instructor to about seven students, the net result would be very large if each teacher would endeavor to become well acquainted with even this number of his students.

Close contact enables the teacher, too, to influence in a pronounced way the point of view of the student, both with reference to his work at the institute and to his ultimate aims. On occasions when I have talked intimately with students about these matters, I have often felt keenly how much more they need advice about *life* than about chemistry. Such individual conversations furnish also the opportunity of giving the student a broader interest by letting him know of the scientific and professional problems in which ourselves and others are engaged. He thus sees more clearly the future before him, and appreciates better the value of the studies he is pursuing.

Though personal contact is by far the most effective way of exerting these general influences, yet, since it is possible to provide for it only to a limited extent, we must improve the opportunities which our regular courses of instruction afford for securing the desired result.

Some of the ways in which this may be accomplished are to indicate the wide scope of scientific generalizations and the beauty of theoretical explanations, to point out the important technical applications of the principles presented, to describe the considerations and experiments which led to their discovery and the participation of individual scientists in their development, and to indicate some of the numerous problems of the science that still await solution. By thus emphasizing the broad scientific aspects, the practical bearing and the historical and biographical development of our existing knowledge, and by impressing the student with the idea that at present "our science is a drop, our ignorance a sea," we may do much to awaken his interest in knowledge for its own sake and to develop in him broader points of view and higher aims. Especially must the importance of these considerations be borne in mind in subjects that have to be presented by formal lectures. I have already indicated my opinion that as a means of imparting a fundamental knowledge and of giving a mental training the lecture plan is strikingly ineffective, and can be justified from these points of view only on grounds of economy. It does, however, have in non-technical subjects what may be called a cultural function of some importance; for it provides, better than the recitation plan, the opportunity of arousing the broader interests of which I have been speaking.

In conclusion, as a summing up of these considerations, I would urge that we take care not to interpret our work as teachers too literally—that we realize that our task is a much larger one than that of imparting a knowledge of our particular subject, and that it is a broader one even than that of developing the power of dealing with its

problems; that, in fact, the most important and most difficult part of our undertaking consists in cultivating sound habits of thought and work, in developing breadth of interest and good judgment, in molding character, and in creating a high moral purpose.

ARTHUR A. NOYES

SOME PRINCIPLES IN LABORATORY CONSTRUCTION[1]

BY common consent, governing boards of colleges recognize that after a main building has been erected, the next should be a chemical laboratory. The artfulness of teachers of chemistry, perhaps aided by their fumes, has caused their colleagues to exhibit little regret and display but minor envy in the placing of the chemistry department under a separate roof. Limited funds and meager equipment caused the erection of the simplest structures at first. The stupendous development of our commercial prosperity and the more general appreciation of the importance of our science, not only in its applications, but as a factor in stimulating the dormant germ of culture in all men, have caused more generous provisions, with consequent elaboration in construction and equipment of chemical laboratories, entailing the most serious responsibility on the part of the professor in charge.

At the outset, I wish to make it plain that all the ideas put forward here have not been incorporated in our new laboratory. Many have. The reasons why the rest have not is of no interest to you. It is generally recognized that architects, however willing they may be, are of little real value in drawing up plans and specifications for laboratories beyond the exterior and artistic effects, as they are very special in their construction and use, of which the designer is naturally more or less ignorant. Our architect, Mr. George B. Post, however, has shown the greatest consideration and willingness to try to accomplish the ends aimed at. Much that I have to say is based upon a close study of laboratories in this country and in Europe. Many ideas we have put into effect have been secured here and there. A few are original.

The plan of a laboratory should be laid down in accordance with the destiny of the institution, as one may judge by its past and by a careful comparative study of the histories of other institutions, keeping in mind not only the immediate demands, but the probable developments within half a century.

LABORATORY PLAN AND ARCHITECTURAL EFFECTS

In the construction of chemical laboratories, different ideas have to prevail, depending entirely upon the immediate object aimed at by the laboratory. A private laboratory may be constructed along any particular lines desired. Undoubtedly a laboratory for the instruction of students in chemical engineering must be different from that used in instructing students of pharmacy or medicine. Most college laboratories, however, should be constructed with the object of giving a general training in chemistry, and not with the idea of training chemists. That should be incidental, which is not the case with technological institutions, where men are trained particularly in that line. Very special rooms, with particularly special apparatus, fixed and movable, must be provided, depending upon the requirements. This paper is concerned with laboratories for colleges in which general and not specific professional training is the aim.

While it is generally considered that a

[1] Read before the New York Section of the American Chemical Society, March 6, 1908.